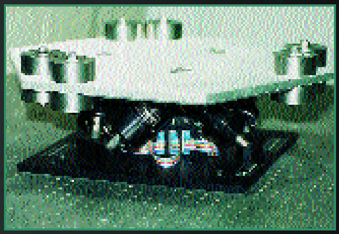


Nineteen ninety-five was a banner year for innovation in the United States. That year, the U.S. Patent and Trademark Office received the largest number of applications for patents and designs to date, according to the 1995 Commissioners' Annual Report. As a result of these applications, 64,562 residents of the United States received patents in such diverse areas as mechanical, electrical, and chemical engineering.[1]

Innovations in these areas offer significant improvements to the transportation, utility, semiconductor, and space industries. Breakthroughs in electrical engineering can facilitate the development of high-speed trains to reduce traffic congestion between major cities. They can also enable superefficient power-control devices to double power line capacity. Innovations in chemical engineering can lead to better materials for vibration suppression in semiconductor manufacturing equipment and can help in deploying inflatable space structures.

Today's Market

Electric utilities and semiconductor manufacturers can benefit greatly from technological innovations. Deregulation is forcing more competitiveness in the electric power industry, which accounted for $208 billion in revenues from retail sales to ultimate customers in 1995.[2] New technologies can help electric utilities establish a competitive advantage, improve efficiency, and trim costs. Reducing production costs is a primary concern for computer chipmakers, whose sales are estimated to reach $197.6 billion in 1999, up from $101.8 billion in 1994.[3] Innovative technologies can suppress vibrations in manufacturing equipment, reducing errors that add to production costs.

Tomorrow's Opportunity

BMDO has funded various technologies for ballistic missile defense that can also provide companies with innovative solutions to help the United States build a stronger economy. The following section describes five examples.

[1]U.S. Patent and Trademark Office. 1995. Setting the course for our future, a Patent and Trademark Office review, Fiscal Year 1995. World Wide Web at http://www.uspto.gov/web/offices/com/annual/annual.html.

[2]Energy Information Agency. 1996. Electric Power Annual 1995, Vol. 1, Chapt. 1. World Wide Web at http://www.eia. doe.gov/cneaf/pubs_html/epa_1995/volume1/chapter1.html.

[3]Semiconductor Industry Association. 1995. Semiconductor forecast summary 1995–1998. World Wide Web at http://www.semichips.org.indstats.htm.

Can You Imagine . . .

. . . a power control device that will help electric utilities reduce power outages and double the capacity of transmission lines.

ELECTRICITY-SAVING CIRCUITS HELP UTILITIES UPGRADE POWER GRIDS

Investigating a flexible alternating current transmission system (FACTS), the Electric Power Research Institute (EPRI) and other groups expect to improve the switching capabilities, capacity, and security of electric utility transmission lines. FACTS controllers also prevent power outages that cascade throughout the distribution system. These devices require highly advanced power electronics to control the flow of current over the transmission lines.

One of the nearest term technologies for FACTS controllers is a high-powered variable switch marketed by Harris Semiconductor Corporation (Melbourne, FL), called the metal oxide semiconductor–controlled thyristor (MCT). Originally funded as a power control device for BMDO's directed energy weapons, MCTs will instantly reroute power to avoid outages and double the capacity of transmission lines. These rugged, reliable, efficient thyristors can operate at higher temperatures and permit faster switching speeds than such conventional thyristors as the silicon-controlled rectifier, the insulated gate bipolar transistor, and the gate-turnoff device.

HARRIS FOCUSES ITS MARKETING EFFORTS FOR THE MCT ON AUTOMOTIVE, ELECTRIC UTILITY, AND MANUFACTURING APPLICATIONS.

Harris launched its first line of MCTs (a 600-volt p-type MCT) in September 1992 and added three more MCT devices, including one 1,000-volt, 65-ampere p-type MCT and two 35-ampere devices (one with and one without a built-in diode). The company soon expects to release a 600-volt, 75-ampere device in a second generation of MCTs. This device will offer a fourfold improvement in switching speed over current generation devices. Harris primarily focuses its marketing efforts for the MCT on automotive, electric utility, and manufacturing applications.

In September 1995, Harris announced plans to invest $250 million in its power semiconductor operation to construct a metal oxide semiconductor (MOS) eight-inch wafer fabrication facility in Mountain Top, Pennsylvania, for MCTs, MOS field effect transistors, and insulated gate bipolar transistors. When fully operational (scheduled for 1997), the facility should create about 120 new highly skilled manufacturing jobs for the community.

Through U.S. Navy funding and a project sponsored by the Defense Advanced Research Projects Agency, Harris and EPRI continue to address further development and packaging requirements for high-power MCTs. Forming much smaller and more powerful power electronic building blocks (PEBBs), the team plans to package MCTs with semiconductor rectifiers and high-performance gate-driver integrated circuits. With such smart power devices as PEBBS, utilities could save $6 billion compared to the cost of adding the same capacity with new lines.[1]

■ Harris' MOS-controlled thyristor may be one solution for upgrading utilities' transmission and distribution systems.

ABOUT THE TECHNOLOGY

Serving as variable-gain switches, thyristors regulate current flow with a technique known as phase control. A significant advance in high-powered electronics, Harris' MOS-controlled thyristors switch much faster, operate at higher power levels, and withstand higher temperatures than conventional thyristors, such as silicon-controlled rectifiers. They handle up to 1,000 volts at more than 100 amperes. Further development could lead to individual devices that handle 2,500 to 4,500 volts at comparable currents. In addition, Harris expects these silicon-based devices to be more easily manufactured than competing power semiconductors.

[1]Hingorani, N. and Karl Stahlkopf. 1993. High-power electronics. *Scientific American*. November, 78–84.

INFLATABLE SPACE STRUCTURES COME OF AGE

Can You Imagine . . .

. . . an inflatable space antenna that is 100 times cheaper than an equivalent mechanically deployed system.

Upon reaching orbit, satellites typically use complex mechanical systems to unfold large communications antennas stowed onboard. Unfortunately, these bulky systems increase the cost and mass of satellites. Also, if rocket launch vibrations exceed upper limits, the antennas could become damaged so that they cannot be fully deployed. L'Garde, Inc. (Tustin, CA), addressed these problems using BMDO-funded technology that inflates structures like a balloon.

L'Garde pioneered the use of inflatable space structures, which can reduce the cost and mass of future spacecraft. This inflatable technology is 10 to 100 times less expensive than mechanically deployed systems, because of its much smaller mass and stowed volume. Also, because an inflatable structure incorporates no moving parts, excessive launch vibrations may not damage it.

L'GARDE RECENTLY TESTED ITS MOST COMPLEX AND PRECISE INFLATABLE SPACE STRUCTURE IN A SPACE SHUTTLE experiment.

The company tested its most complex and precise inflatable space structure in an experiment carried onboard the space shuttle *Endeavor*. L'Garde built the inflatable antenna experiment (IAE) under a $9-million contract from NASA's In-Space Technology Experiment Program. Goddard Space Flight Center integrated IAE into its Spartan 207 spacecraft. *Endeavor*'s astronauts used a robotic arm to release Spartan into free flight, which set the stage for deploying the IAE.

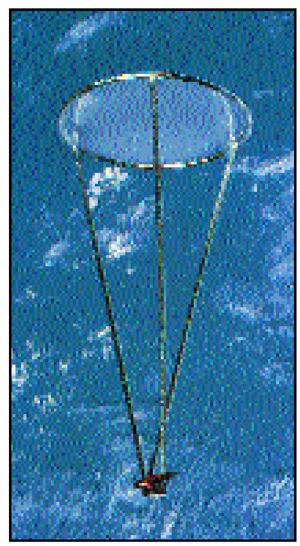
The IAE achieved its proper configuration, and pictures taken from *Endeavor* gave ground control personnel a spectacular sight. However, before L'Garde considers the IAE operational, it must resolve some apparent glitches in the deployment and conduct further testing. Despite these problems, the IAE demonstrated many advantages of inflatable structures. The antenna stowed away in a 7 x 3 x 1.5 foot box, but inflated to the size of a tennis court; the whole deployment system weighed only about 132 pounds; and it cost 100 times less than an equivalent mechanically deployed system.

The IAE is just one example of the many space structures that could benefit from L'Garde's inflatable technology. Other possible inflatable structures include solar arrays, solar concentrators, support struts, and sunshades. The Defense Advanced Research Project Agency funded L'Garde to develop and test the first inflatable solar array with an output of 200 Watts and power density of 90 to 100 Watts per kilogram.

Having worked with space inflatables since 1971, L'Garde has tested more than 100 inflatable structures for government clients. The company developed much of the basic technology that underlies all of its inflatable systems in several BMDO projects to build decoys of ballistic missiles for sensor and interceptor studies.

ABOUT THE TECHNOLOGY

L'Garde's inflatable systems can be packaged in compact containers; a gas inflates the clear or metallic structural film. Inflatable structures do not need the mechanical parts that conventional systems do—an important feature on a spacecraft, where any mechanical difficulty can ruin a mission. When required, structures can be made rigid through several methods, including the use of ultraviolet (UV) light-sensitive epoxy upon inflation. When exposed to plentiful UV rays in space, the epoxy hardens. Once hardened, the support struts act as one solid structure, holding the structure fast without the need to maintain inflation pressure.



■ The IAE experiment, shown here following its deployment from the space shuttle *Endeavor*, will lay the groundwork for future technology development in inflatable space structures.

Can You Imagine . . .

. . . a vibration isolator that can provide a stable environment for precision lithography equipment and can control vibrations in medical imaging devices.

LEVERAGING ITS EXPERTISE IN ACTIVE AND PASSIVE VIBRATION SUPPRESSION, CSA FORMED A STRATEGIC ALLIANCE WITH NEWPORT CORPORATION.

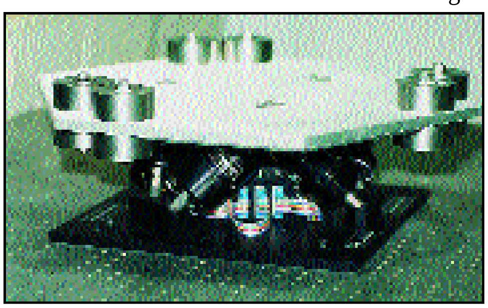
BMDO SPACE R&D RESULTS IN ULTRAQUIET EQUIPMENT

Advances in lithography have enabled the miniaturization of computer chips. Shrinking the circuit elements on these chips has resulted in tighter acceptable alignment tolerances for lithographic equipment, making the lithography process even more sensitive to vibration. Thus, chip makers are searching for new ways to keep their equipment isolated from excessive vibrations that can lead to flawed products. In a $151-billion industry that grew 37 percent in 1995,[1] throwing away even a small percentage of those chips is costly.

CSA Engineering, Inc. (Palo Alto, CA), developed an electromechanical control system that can control vibrations in precision lithography equipment. The system can also be used in other applications, such as cellular base station receivers and airborne sensors. It was derived from CSA's UltraQuiet Platform (UQP), a six-axis vibration isolation system for space-based sensors originally developed with BMDO SBIR funding.

The UQP system uses a novel combination of passive and active vibration suppression devices connected serially within each of six struts. This passive-active combination allows the use of high-force, short-stroke actuators, giving the UQP system superior performance over passive-only, active-only, or parallel passive-active systems. It also makes the control system less sensitive to vibrational modes of the isolated instrument or machine.

Leveraging its expertise in vibration suppression, CSA formed a strategic alliance with Newport Corporation, which sells precision optical equipment. This alliance, which has already resulted in several small product-development projects, could grow significantly during the next few years. For example, the team may invest a large amount of time and capital in developing the next generation of active vibration-suppression equipment for the precision lithography machinery used in manufacturing semiconductors.



■ CSA Engineering's UQP system, pictured above, uses a novel combination of passive and active devices connected serially to suppress vibration.

CSA has investigated excessive vibrations in the cooling system of a newly developed magnetic resonance imaging machine and created several technology fixes for it. The company is currently developing vibration isolation technology for the cryocoolers used to cool superconducting switches and junction boxes in base stations for cellular communications.

ABOUT THE TECHNOLOGY

The UQP system uses a novel combination of passive and active vibration-suppression devices connected serially. This six-legged, spider-shaped flexure provides the passive isolation to an intermediate stage. The system measures the damped motion of this stage and feeds it to the control circuitry for a base-mounted actuator that serves as an active isolator. The intermediate stage and the serial mounting reduce the amount of displacement the actuator must counter, making the system more efficient than either passive-only, active-only, or parallel passive-active systems. It also does a better job of canceling vibrational modes that arise in flexible payload structures.

The UQP system works optimally for stroke displacements of 25 to 50 microns (1 to 2 mils), frequencies greater than 5 Hz, and payloads of up to 100 pounds. It integrates all of the mechanical actuators, dampers, and electrical control components into a platform less than six inches high. A version of the UQP system designed for payloads up to 15,000 pounds would double the height.

[1] Singer, Peter H. 1996. Dataquest revises 1996 chip forecast sharply downward. *Semiconductor International*, June.

NEW TRANSISTOR TAKES THE HEAT

Can You Imagine . . .

. . . a new transistor that operates at temperatures over 500˚C.

Car makers would like to put electronics deeper into engines to keep a closer watch on control and exhaust functions. However, the silicon transistors used in these systems cannot operate above 150˚C, and their performance may start dropping off at around 80˚C. New transistors that operate above 500˚C would allow car makers to move electronic control systems closer to engines.

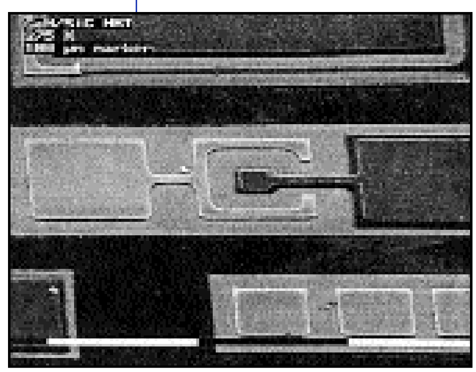
Researchers at Astralux, Inc. (Boulder, CO), have tested a new transistor up to 535˚C, as high as their equipment permitted. The transistor's much higher temperature range results from its materials: silicon carbide (SiC) and gallium nitride (GaN), two semiconductor materials particularly suited to operation at high temperatures. The BMDO SBIR program funded the research and development of this technology, which could provide high-temperature electronics for missile defense control systems.

ASTRALUX WELCOMES STRATEGIC PARTNERS OR LICENSEES TO HELP MARKET THE DEVICE.

The new transistor will have important uses in a growing number of high-temperature environments in the automotive and aerospace industries. For example, Astralux says the technology may control the power delivered to motors in future electric cars, replace hydraulic systems with electric motors, and eliminate the need for heavy, expensive cooling systems in space electronics. Future innovations, such as fabricating several transistors on a single chip, may allow high-temperature digital circuits.

The same characteristics that allow the new transistor to operate at high temperatures will also allow it to operate at high frequencies and high powers. Astralux began to address these capabilities in two recently awarded SBIR Phase I contracts. The company is also looking at high-frequency possibilities for the device.

Astralux plans to sell various high-temperature transistors when it resolves several packaging issues, the first quarter of 1997. Meanwhile, the company welcomes strategic partners or licensees to help market the device.



■ The high-temperature transistor has construction similar to silicon bipolar transistors, except that it is made of large-bandgap materials.

ABOUT THE TECHNOLOGY

The high-temperature capabilities of Astralux's heterojunction bipolar transistor (HBT) come from the materials used as the heterojunction. Generally, a material's band gap limits the transistor's operating temperature range. Silicon's band gap of 1.1 electron volts (eV) translates into a maximum operating temperature of around 180˚C. SiC and GaN, with band gaps of 2.9 eV and 3.4 eV, respectively, allow transistors to work at much higher temperatures.

The HBT uses SiC for the base and collector; GaN may also be used for the collector. Because GaN's band gap is wider than SiC's, a barrier blocks hole current flow from the base to the emitter, increasing the electron injection efficiency in the transistor. Higher emitter efficiency results in higher current gain. At room temperature, the HBTs have a current gain of over 10 million, while at 535˚C the gain is still around 100.

Can You Imagine . . .

. . . a high-speed train that would cost far less than a magnetically levitated train.

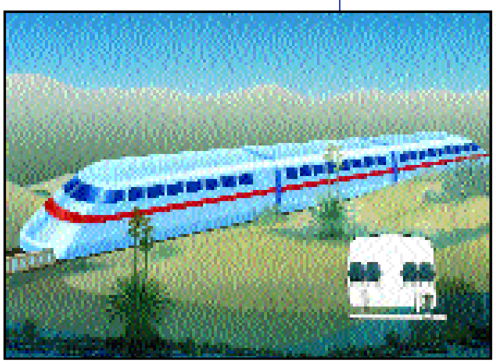
BMDO-FUNDED R&D MAY GET FAST TRAINS BACK ON TRACK

For years, magnetically levitated (maglev) trains fostered high expectations of state and Federal transportation planners, because the trains could reach speeds up to 300 mph. Zipping along new tracks, maglev trains could relieve increasing airport and highway congestion between major cities 200 to 600 miles apart. In 1994, air passengers traveled 170 billion miles more than they did in 1970—an increase of 87 percent. Automobile use overshadows all other transportation modes, growing by over 900 billion passenger-miles in the last 24 years.[1]

However, obtaining rights-of-way to lay new track and laying the track itself may cost tens of millions of dollars per mile, pushing this technology out of reach for cash-starved governments. For example, Florida's Department of Transportation derailed a proposed maglev train to transport tourists from the Orlando International Airport to Walt Disney World Amusement Park in 1994 when the price reached $1 billion.

TO TEST THEIR IDEAS, SANDIA RESEARCHERS BUILT AND TESTED A MODEL THAT REACHED A SPEED OF 34 MPH IN JUST 12 FEET.

Sandia National Laboratories (Albuquerque, NM) has proposed a new high-speed train that runs on today's rail lines for a fraction of the cost of maglev systems. A segmented-rail phased-induction motor, called Seraphim for short, is the keystone of Sandia's proposal. The motor provides the electromagnetic induction required to propel the new train on conventional wheels and rail. Sandia developed this technology as part of a BMDO electromagnetic "gun" for launching projectiles into space at speeds around one kilometer per second.



■ Pictured above is an artist's concept of Sandia's high-speed train, which could easily reach 300 mph on today's rail lines.

Construction and maintenance costs comprise a large portion of the maglev train's price tag, because it must run on electrified tracks. Sandia projects that its approach, which combines existing track with inexpensive aluminum plates mounted alongside or between the rails, would cost 75 percent less than a maglev system. This approach also allows old-style and new-style trains to travel on the same tracks. In the Seraphim scheme, electromagnets on the locomotive generate accelerating forces between the track plates and the vehicle, pushing the train to 200 mph. With new precision rails, the train could easily reach 300 mph—just as fast as maglev trains.

To test their ideas, the Sandia researchers built and tested a crude model that reached a speed of 34 mph in just 12 feet. To get out of the lab and onto the rails for real-world experiments, Dr. Barry Marder, the physicist heading the project, expects to raise $1 million from private investors and other organizations.

ABOUT THE TECHNOLOGY

In the Seraphim train concept, a segmented aluminum rail mounted alongside or between the rails interacts with powered coils on the train, causing acceleration. Pulsing the current through the coils as they cross the edges of the rail induces surface currents that repel them. The pulse through the coils must occur in synchronization with the relative movement over the rail segments. Sense-and-fire optical circuits, controlling the pulsing of the power modulators, provide this synchronization. The repulsion between the rail segments and magnets propels the train forward. This electromagnetic propulsion technology allows the train to achieve high speeds in relatively short distances. Reversing the phasing of the coil pulsing provides efficient braking.

[1]Lakshmanan, T.R. 1996. Statement of T.R. Lakshmanan, Ph.D., Director, Bureau of Transportation Statistics, Department of Transportation before the Subcommittee on Surface Transportation Committee on Transportation and Infrastructure, U.S. House of Representatives, Washington, DC, 28 March.